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FECUNDITY OF THE PACIFIC SARDINE
(*Sardinops caerulea*)

By JOHN S. MACGREGOR

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ABSTRACT

Diameter measurements of ovarian ova were made for 587 female Pacific sardines (*Sardinops caerulea*) obtained from the San Pedro commercial fishery samples for the period November 10, 1945 through February 27, 1946. The number of ova present in the most advanced group of developing ova were counted for 116 sardines that contained a distinct group of such ova. The calculated number of ova present in this group increased with age, length, and weight of the fish. The fecundity-length correlation was better than the fecundity-age correlation, and the fecundity-weight correlation was better than either of these. Fecundity-length regression lines based on four different formulas and fecundity-weight regression lines based on two different formulas are compared.

Data on age and length at first maturity based on the criterion of degree of ovarian ovum development are presented.

CONTENTS

	Page
Introduction	427
Material and equipment	427
Methods	427
Relation between fecundity and length	431
Relation between fecundity and weight	435
Comparison of fecundity-length and fecundity-weight regressions	436
Relation between fecundity and age	439
Number of spawnings per year	440
Length at first maturity	445
Age at first maturity	447
Summary	448
Literature cited	448

FECUNDITY OF THE PACIFIC SARDINE (SARDINOPS CAERULEA)

By John S. MacGregor, *Fishery Research Biologist*

Extensive studies of the biology of the Pacific dine (*Sardinops caerulea*), designed to lead to understanding of the causes of fluctuations in size and distribution of the population, have n carried on since 1949 under the sponsorship the California Marine Research Committee. ese studies, the California Cooperative Oceanic heries Investigations, have been made by the ifornia Academy of Sciences, the California partment of Fish and Game, Hopkins Marine tion of Stanford University, Scripps Institution Oceanography of the University of California, l the South Pacific Fishery Investigations of U. S. Fish and Wildlife Service.

One of the requisites of these studies is a measure he size of the sardine population. The number individuals in a spawning population of fishes be estimated if the following are known: (1) total number of eggs produced per year by all nales in the population, (2) the average number eggs produced per year by each female in the pulation and (3), the sex ratio in the population. is method has been one of those used for several ars by the South Pacific Fisheries Investigations estimate the size of the Pacific sardine popula- n along the coast of California and Baja Cali- nia. To determine the average number of eggs oduced per year by each female it is necessary determine the average number of eggs spawned batch and the number of batches produced. e annual egg production per female used in the pulation estimates has been based on fecundity ta for eight female sardines given by Clark 34). The purpose of the present paper is to ord more extensive data on the fecundity of Pacific sardine (item number 2 above).

I wish to express my appreciation to my col- gues, E. H. Ahlstrom and T. M. Widrig for pful suggestions, F. E. Felin for making the e determinations, A. M. Vrooman for assisting counting and measuring the eggs and preparing e figures, and W. M. Morton for collecting the terial, and to members of cooperating agencies their assistance.

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MATERIAL AND EQUIPMENT

The 13 samples of sardines examined were taken from the commercial fishery at San Pedro, Calif., in November and December, 1945, and January and February, 1946, and included 1,270 individuals. These fish, originally collected for a morphometric study, were fixed and preserved in formalin in gallon jars. Some of them were subsequently transferred to alcohol.

Ovaries and ovary samples for ovum counts and diameter measurements were weighed on a Sartorius Selecta balance. The ovum counts and diameter measurements were made on projected images of the ova using the scale reading device described by Mosher (1950).

The ovary samples were placed on microscope slides for weighing and projection. Slides were prepared by placing two threads parallel to each other and to the long axis of the slide, along one surface of the slide, and securing them at the ends with cellophane tape. The threads were spaced a distance apart somewhat less than the diameter of the microscope field and served as guide lines. The use of threads rather than etched lines kept the ova from falling on the line and controlled the spread of the mounting medium.

METHODS

A pair of ovaries was drained for a few minutes on paper toweling and weighed to the nearest 0.001 gram. A small sample from one ovary was then placed on a microscope slide and weighed to the nearest 0.0001 gram. A drop of glycerin was placed over the sample; the ova were teased out and spread into three strips separated by the two guide-line threads. A second microscope slide was then placed over the first and the two slides were fastened at the ends with cellophane tape. The formalin-hardened ova were not distorted between the slides prepared in this manner so long as the pressure applied to the slides was not excessive. A second mount was prepared in a similar manner, using a sample from the other of the pair of ovaries. The use of two samples for each pair of ovaries

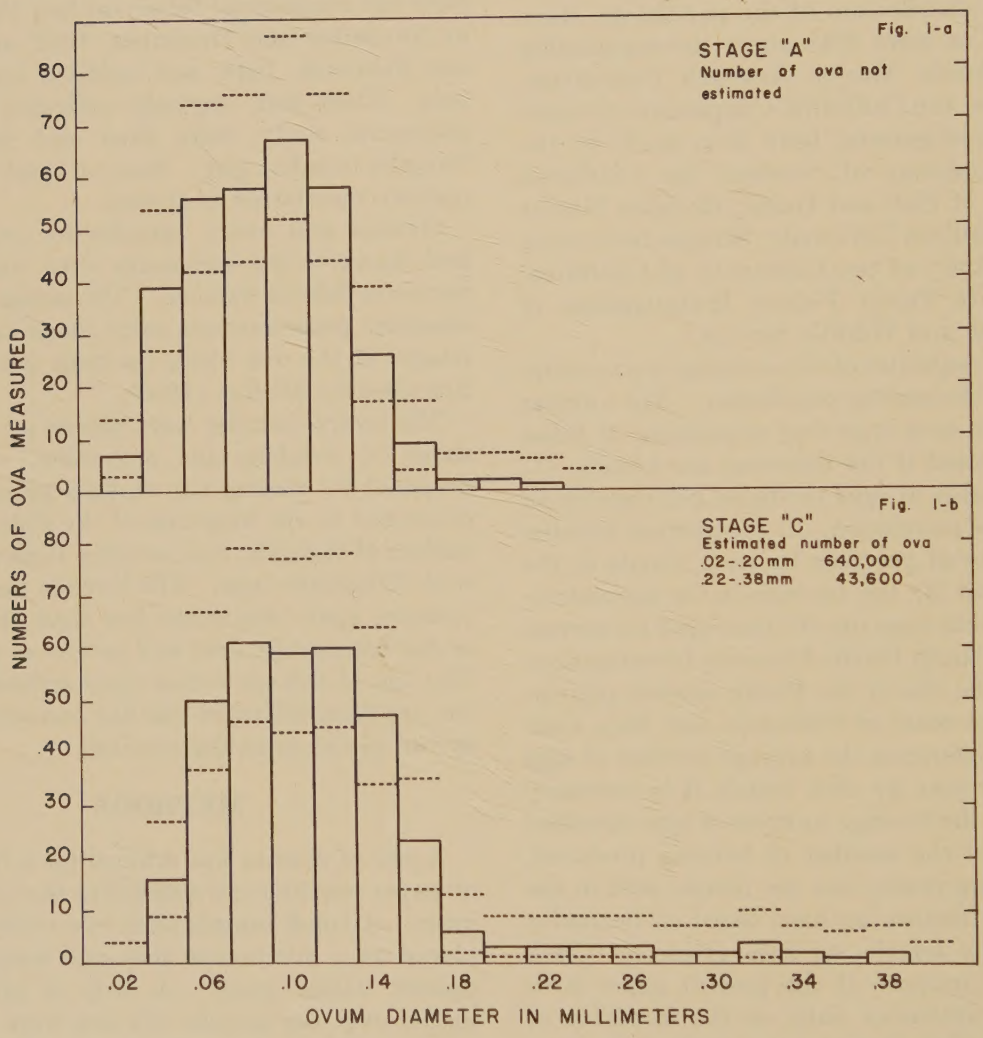


Figure 1–a, b.—Sardine intra-ovarian ovum diameter frequencies.

ɔvided a check on the accuracy of the ovum ınts and yielded a larger sample than could ve been easily examined on one slide.

Each sample of ova was projected in the scale ɔjector at a magnification of 50X. The pro-ted ovum diameters were measured to the ırest millimeter. When doubled, this measure-nt gives the actual ovum diameter in hun-ɛdths of a millimeter by 0.02 mm. units.

If the sample of ova contained no distinct (by e) group of developing ova, the diameters of the ger ova in the sample were measured. The gest ovum diameter was used as a measure of e ovarian development for these early stages ıen no modal or other central value could be tained. Figure 1–a and b and figure 2–a and b ɔw ovum diameter frequencies from ovaries in ese stages of development. The dotted lines in figures 1 and 2 represent 95 percent confidence limits of the counts.

If the ovary was advanced enough so that a distinct group of yolked ova had differentiated by size from the smaller yolked ova, enough ova (generally 100 to 200) 0.22 mm. or larger (i. e., containing yolk) were measured to delimit clearly this most advanced group of developing ova. When the size range of this group was determined, all ova in that size range on the slide were counted. Figure 2-c, d, e, f, g, and h shows ovum diameter frequencies from ovaries in these stages of development.[1] The most advanced groups of ova shown in these figures consist of opaque ova except the group shown in figure 2–h which consists of translucent ova. No perivitelline space has formed in

[1] The multimodal distribution of diameters of developing intraovarian ova of the Pacific sardine was first demonstrated and figured by Clark (1934).

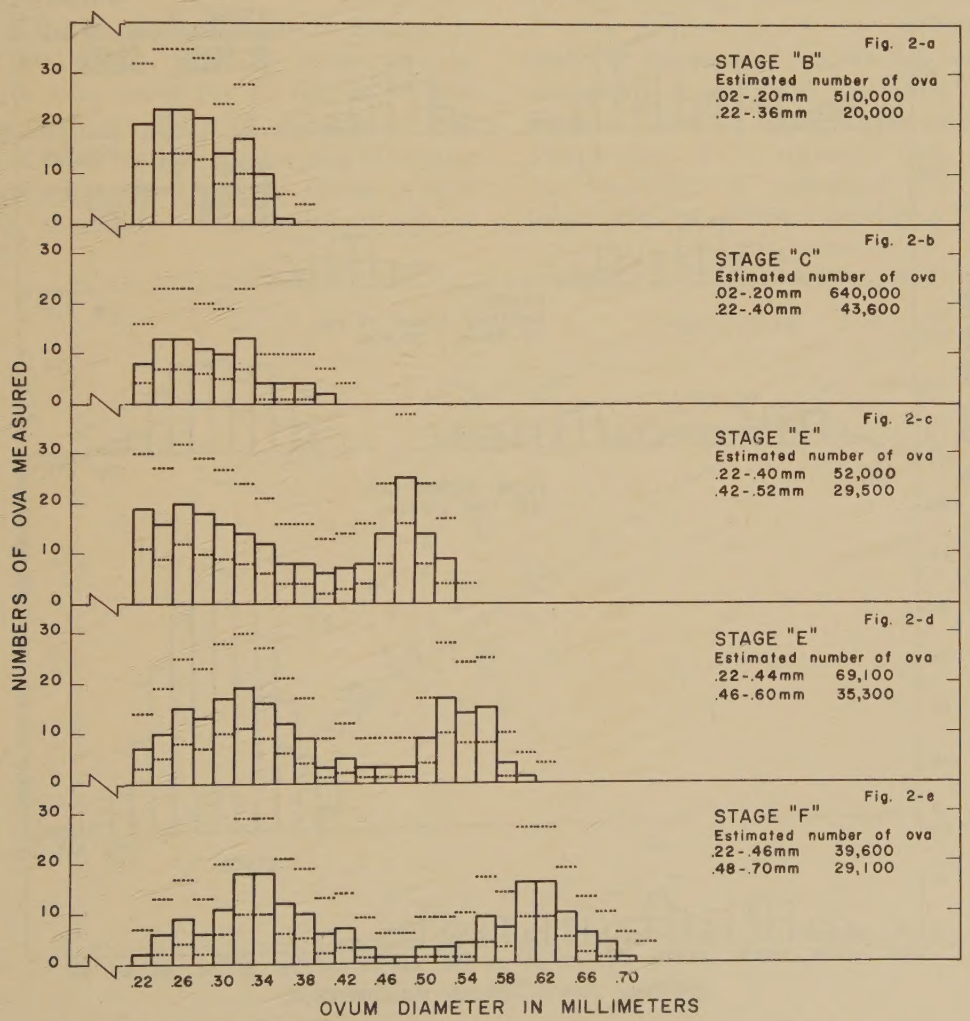


Figure 2–a, b, c, d, e.—Sardine intra-ovarian ovum diameter frequencies (see p. 430).

the intraovarian ova, and hence the ovum diameters are also yolk diameters. In figure 2–i yolk-diameter distributions of 343 planktonic sardine ova in early developmental stages are shown for comparison with figure 2–h.

Figure 2–j shows the ovum diameter distribution of degenerating ova from the ovaries of a sardine taken in May of 1951. None of the San Pedro 1945–46 sardines used in this study were found to be in this condition.

Clark (1934) grouped developing ova in the largest mode into twelve stages of maturity. As I will have occasion to refer to some of these stages in comparing my observations with those of Clark, I am including a description of these stages:

IMMATURE

Stage A: Frequencies with a mode between 0 and 0.2 m only.

MATURING (OPAQUE EGGS)

Stage B: Frequencies with the last mode between—0 and 0.26 mm.

Stage C: Frequencies with the last mode between—0 and 0.34 mm.

Stage D: Frequencies with the last mode between—0 and 0.44 mm.

Stage E: Frequencies with the last mode between—0 and 0.54 mm.

Stage F: Frequencies with the last mode between—0 and 0.64 mm.

Stage G: Frequencies with the last mode between—0 and 0.74 mm.

Stage H: Frequencies with the last mode between—0 and 0.84 mm.

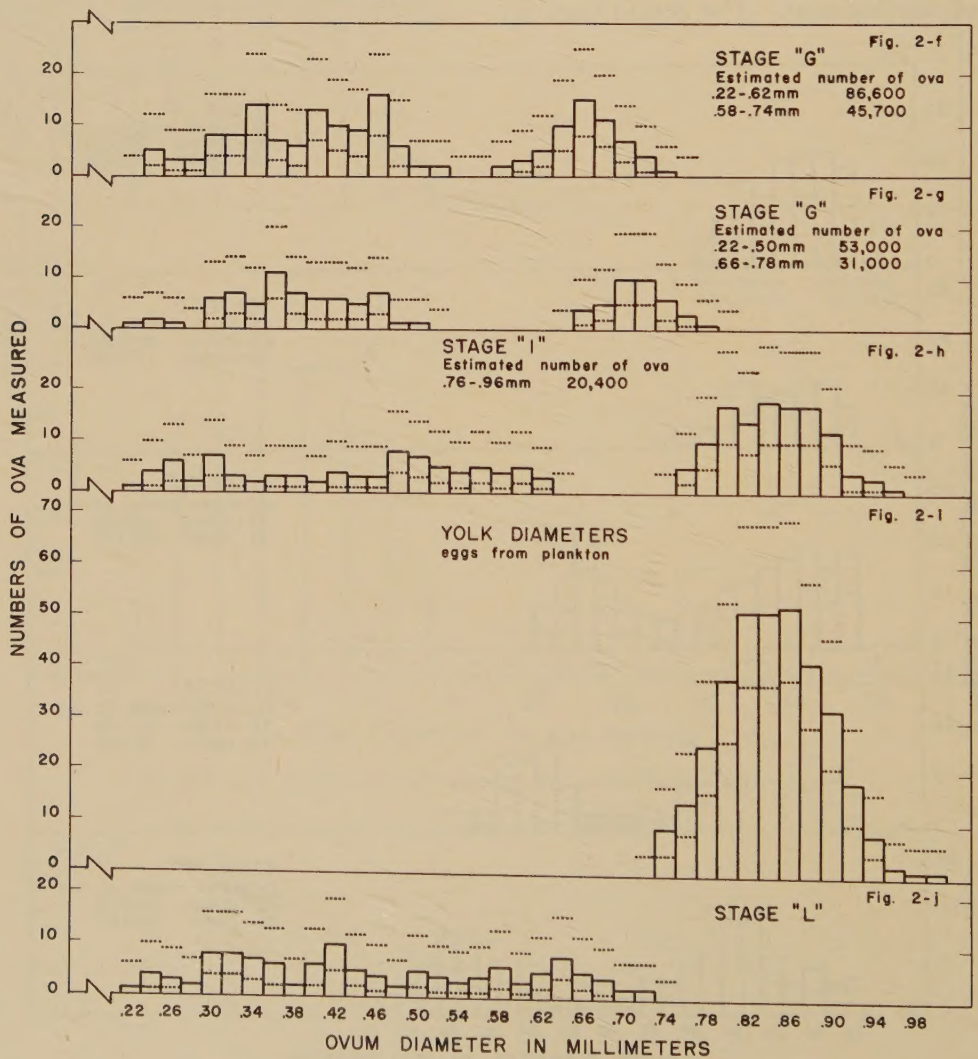


FIGURE 2–f, g, h, i, j.—Sardine ovum diameter frequencies.

MATURING (TRANSPARENT EGGS)

ıge I: Frequencies with the last mode between 0.84 and
).94 mm.

ıge J: Frequencies with the last mode above 0.94 mm.

MATURE (TRANSPARENT EGGS FREE IN THE OVIDUCT)

ıge K: Frequencies with the last mode above 0.94 mm.
ınd the ripe eggs segregated.

SPENT

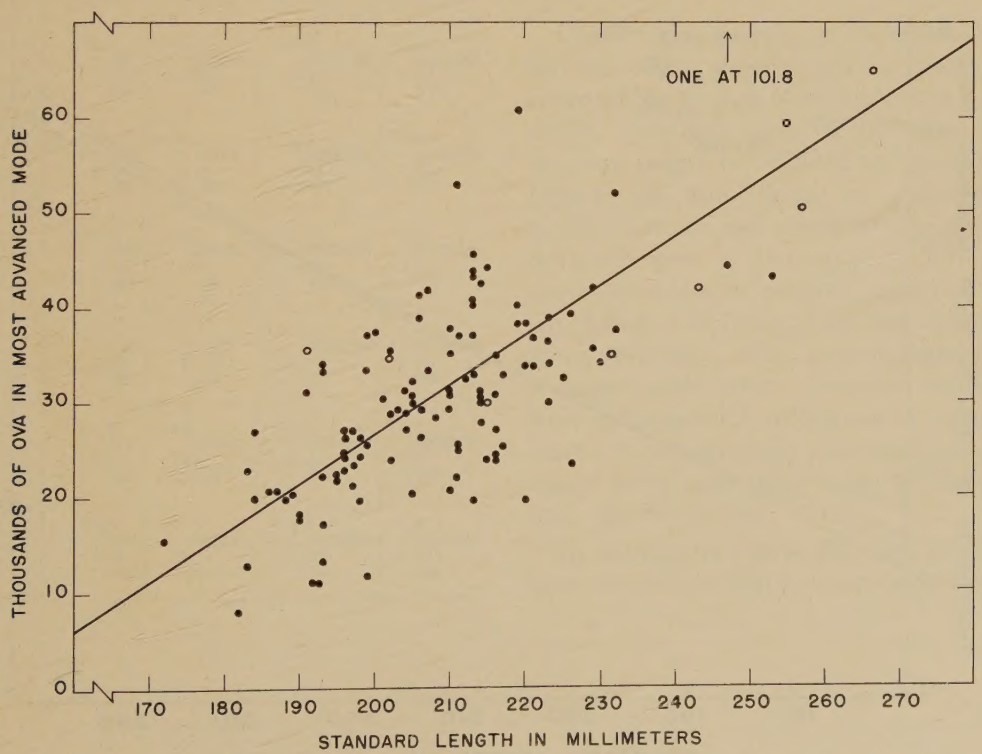
ıge L: Frequencies with ova larger than 0.20, but these
ggs degenerating.

The number of ova in the most advanced group
ıs calculated by multiplying the weight of the
aries by the number of these ova in both
mples and dividing by the total weight of
th samples. It was also determined from each
the two samples separately as a check on the
mpling variation.

All (587) of the female sardines in the 13 samples
re used for ovum diameter measurements.
vum counts were made for all fish (116) that
ntained a distinct group of developing ova.
ıe weight of both samples from a pair of ovaries
ualled approximately 2 percent of the weight
that pair of ovaries. The deviations of the 116 pairs of ovum estimates from their respective combined estimates was 1,700 eggs at one standard deviation level. The right and left ovaries of each pair were at the same stage of maturity in every case, and neither ovary gave a consistently higher or lower count than the other. As pointed out by Clark (1934), there are no apparent differences in the relative numbers of ova in each size group in the different parts of the ovary.

RELATION BETWEEN FECUNDITY AND LENGTH

Figure 3 shows 116 fecundity observations obtained from the January and February, 1946, samples plotted against their respective fish lengths. The regression line, fitted by the method of least squares, of the form $Y=a+bX$ (where Y=the number of ova in the most advanced mode in thousands, X=the fish length in millimeters and a and b are constants) is also shown. Clark's (1934) 8 observations are plotted for comparison. It is apparent from figure 1 that the fecundity of individual fish of the same length can vary considerably. This variation



ıURE 3.—Relation between fecundity and standard length for 116 sardines (San Pedro, Jan.-Feb., 1946). Open circles are Clark's (1934) observations.

(S_y=8.76 thousands of ova) is more than 5 times as large as the variation attributable to sampling and counting techniques.

There has been some differences of opinion among various authors as to whether length, length squared, or length cubed should give the best straight line correlation with fecundity. Lehman (1953) correlated the fecundity of 22 shad (*Alosa sapidissima*) with their lengths. His equation (least squares) for the line of average relationship is $Y=-462.691+40.090X$ in which Y=the number of ova in thousands, and X=the length in inches.

Clark (1934:21), referring to eight fecundity observations on the Pacific sardine, states:

> By the method of least squares from the formula $N=FL^x$, where N indicates the number of eggs; L, the length; F, a constant; and x, the exponent expressing the relationship between the number of eggs and the length of the fish; x was found to have a value of 1.9868. This suggests that the numbers of ova produced by individual sardines increase as the square of the length. But because the calculations were based on very scanty data, these conclusions can be tentative only.

Simpson (1951) expressed fecundity observations for 256 plaice (*Pleuronectes platessa*) by the formula $F=KL^3$, where F=the number of ova, K, a constant; and L^3, the cube of the length of the fish.

The line of best fit (least squares) for the 11 sardine fecundity observations is plotted in figure 4 for each of four different relationships.

Table 1 gives the Y-intercepts (a), slopes (b), standard errors of estimate of Y (S_y) and coefficients of correlation (r) of the four lines for the 116 fish and for each of the five samples which together constitute the 116 fish. The standard errors of estimate of Y for 10-millimeter length intervals are presented in table 2. Table 3 gives the number of ova in the most advanced group calculated by each of the four different formulas at each of 9 different 10-millimeter length intervals. It is apparent from these comparisons that convenience, rather than theoretical considerations should be the deciding factor in selecting one of the regression formulas to describe these data. The same is true for Lehman's (1953) fecundity

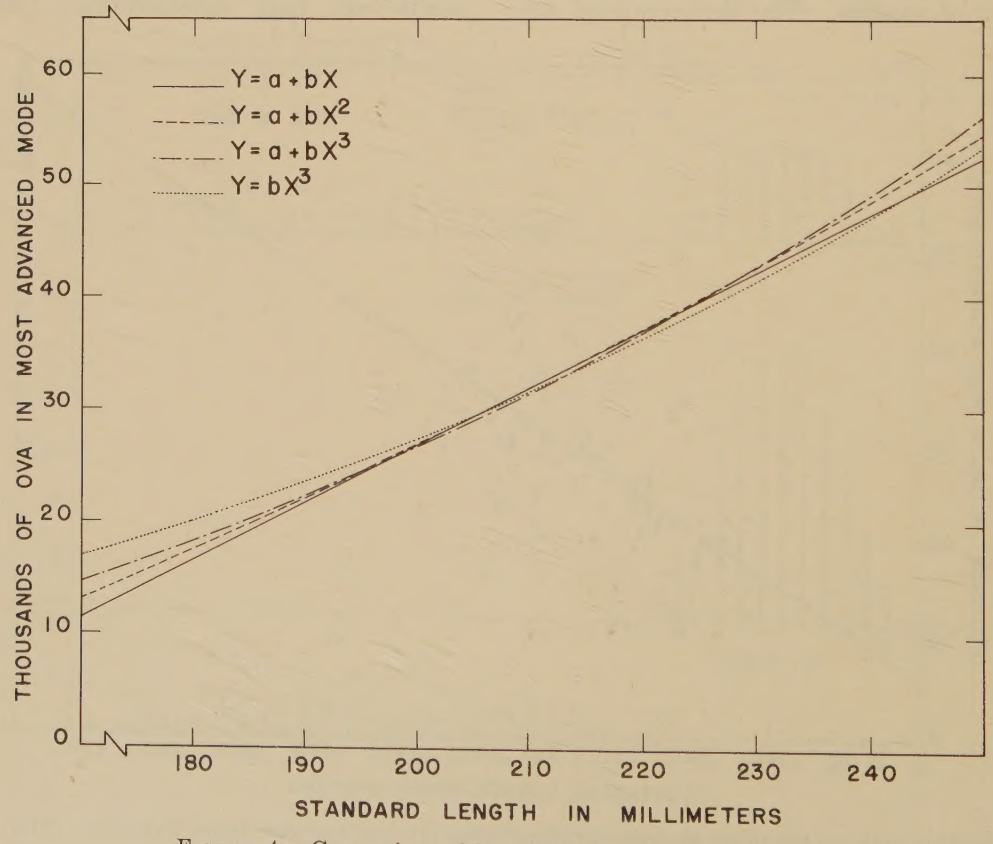


FIGURE 4.—Comparison of fecundity-length regression lines.

ata for shad. Using his formula $Y=a+bX$, =40.2 and $a=-462.7$. Using $Y=a+bX^3$, =39.3 and $a=19.0$. As a approaches zero the rmula $Y=bX^3$ would also give an S_y approxiating the above two.

Theoretically the number of ova is dependent on the volume of the ovary, a three-dimensional nction, and therefore should better correlate with e cube of the length, length itself being, of urse, only linear. In Simpson's (1951) paper on e fecundity of the plaice, the straight line reession of fecundity on length cubed is considerly better than that of fecundity on length quared or length. The significant differences etween the regressions in this case are brought t by the greater relative range in sizes of fish sed in calculating the regression lines. Measured a percentage of the length of the shortest fish sed, the range of Simpson's plaice is 162 percent, at for Lehman's shad is only 66 percent and for e 116 sardines 48 percent (56 percent including lark's 8 fish).

ABLE 1.—*Comparison of some possible fecundity-length relationships*

Sample	$Y=a+bX$	$Y=a+bX^2$	$Y=a+bX^3$	$Y=bX^3$
-8 (17 fish)				
(thousands)	−25.4	−1.4	+6.6	0.0
	.239	.000594	.00000195	.00000267
(thousands)	5.33	5.32	5.30	5.48
	.547	.549	.553	.510
-9 (9 fish)				
(thousands)	−112.9	−44.9	−22.3	0.0
	.668	.00164	.00000534	.00000265
(thousands)	5.02	5.02	5.03	5.97
	.786	.786	.785	.677
-11 (41 fish)				
(thousands)	−43.1	−4.3	+8.6	0.0
	.358	.000825	.00000253	.00000338
(thousands)	5.49	5.50	5.49	5.60
	.478	.476	.478	.445
-12 (5 fish)				
thousands)	−87.8	−27.7	−7.4	.0
	.574	.00137	.00000430	.00000352
(thousands)	4.09	4.16	4.29	4.44
	.839	.833	.822	.808
-13 (44 fish)				
(thousands)	−104.3	−32.1	−8.0	0.0
	.674	.00156	.00000475	.00000386
(thousands)	10.2	10.3	10.4	10.6
	.730	.725	.719	.703
l samples (116 fish)				
(thousands)	−76.0	−22.9	−4.3	0.0
	.514	.00124	.00000386	.00000341
(thousands)	8.76	8.74	8.75	8.79
	.641	.643	.642	.638

TABLE 2.—*Standard error of estimate of Y for ten millimeter length intervals using formula: $Y=a+bX$*

[Y=No. of ova in thousands; X=length in mm.]

Length (mm.)	Fish (number)	S_y (thousands)
170–179	1	
180–189	10	4.68
190–199	27	6.60
200–209	21	6.80
210–219	36	8.91
220–229	15	7.33
230–239	3	
240–249	2	
250–259	1	
Total	116	8.76

TABLE 3.—*Calculated number of ova in most advanced mode for sardines of different lengths*

Length (mm.)	Number of ova (in thousands)			
	$Y=a+bX$	$Y=a+bX^2$	$Y=a+bX^3$	$Y=bX^3$
170	11.4	12.9	14.7	16.8
180	16.5	17.3	18.2	19.9
190	21.7	21.9	22.2	23.4
200	26.8	26.7	26.6	27.3
210	31.9	31.8	31.4	31.6
220	37.1	37.1	36.8	36.3
230	42.2	42.7	42.7	41.5
240	47.4	48.5	49.1	47.1
250	52.5	54.6	56.0	53.3

Obtaining a sample of Pacific sardines suitable for fecundity determinations with a size-range comparable to that of plaice would be an impossibility. The size range of the sample of spawning sardines might be doubled by including large fish (270 to 290 mm.) from the northern part of the sardine's range and small spawning fish from the southern part of the range. (I have examined some 145–155-mm. sardines taken off the southern tip of Baja, California, that had apparently developing gonads.) This procedure could introduce a considerable error. Simpson found that there were geographical differences in fecundity among stocks of plaice, those from the Baltic containing many more eggs than those of comparable sizes from the North Sea.

In figure 5 the data for each of the 5 samples have been described by regression lines, using the

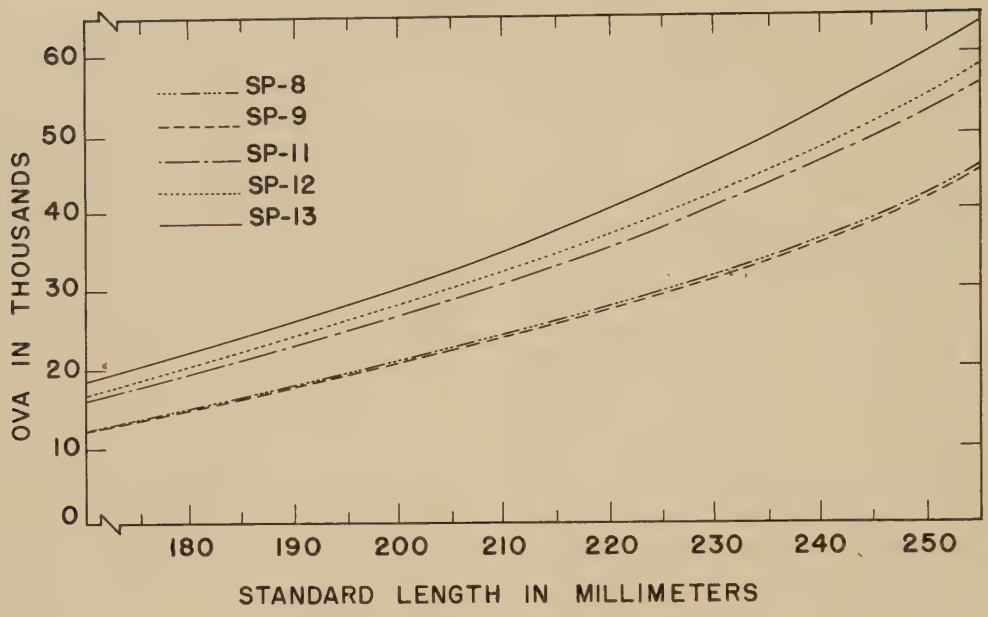


FIGURE 5.—Fecundity-length regression $Y=bX^3$.

formula $Y=bX^3$. The use of this formula makes the curves much easier to compare, since the Y-intercept is taken as zero for all samples and the slopes may be compared directly.

When the curve is fitted by the least squares method to the data, using the formula $Y=a+bX^3$, both the a and b values are determined by the data. The sum of the plus deviations will equal the sum of the minus deviations, while the sums of the squares of the deviations will be at a minimum. When the formula $Y=bX^3$ is used, the Y-intercept is forced to be zero, and both of these conditions cannot be met if the distribution of data is at all skewed. A regression line about which the sum of the plus deviations equals the sum of the minus deviations can be obtained using a value obtained from the formula $b=\frac{\Sigma Y}{\Sigma(X^3)}$. A line about which the sum of the squares of the deviations is at a minimum can be obtained using $b=\frac{\Sigma(X^3Y)}{\Sigma(X^3)^2}$. Although there is little difference between the b values derived by these two methods [2] from the data for the 116 sardines, the latter method has been used because the standard errors of estimate and correlation coefficients based upon it should theoretically be more nearly comparable with those obtained in conjunction with the least squares methods in which the Y-intercept is determined by the data.

Figure 5 shows that samples SP–8 (Jan. 11) and SP–9 (Jan. 24) almost coincide and that samples SP–11 (Feb. 9), SP–12 (Feb. 21), and SP–13 (Feb. 27) show an apparent increase in fecundity as the season progresses. Because of the restricted range of lengths and the great variation in ovum counts at any given length, no significance is attached to this apparent temporal fecundity increase. In figure 6 are plotted the regression lines for each of the 5 samples, fitted (least squares) by the formula $Y=a+bX$ (which differs most from the formula $Y=bX^3$). In table 4 each of the 10 possible combinations of pairs of b's is compared by t test for the possibility of significantly different slopes for both formulas. There are no pairs of regression slopes that are significantly different when both formulas are taken into consideration. The apparent significant differences in the slopes of the pairs, SP–8 and SP–9, and SP–8 and SP–13, when the formula $Y=a+bX$ is used are primarily a result of the comparatively great variation in b values and the restricted range in X values.

[2] Simpson apparently used the formula $b=\Sigma\left(\frac{Y}{X^3}\right)\div N$ which also gives a b value differing very little from the other two for the 116 sardines.

TABLE 4.—*Comparison of regression coefficients*

Sample	n	$Y=a+bX$		$Y=bX^3$	
		t	P	t	P
-8	22	1.944	<.05	0.0085	<.9
-9					
-8	54	0.834	<.4	0.652	<.5
-11					
-8	18	1.359	<.1	0.433	<.6
-12					
-8	57	2.411	<.01	0.803	<.4
-13					
-9	46	1.381	<.1	0.400	<.6
-11					
-9	10	0.313	<.7	0.321	<.7
-12					
-9	49	0.016	<.9	0.404	<.6
-13					
-11	42	0.859	<.3	0.072	<.9
-12					
-11	81	0.559	<.4	0.363	<.7
-13					
-12	45	0.235	<.8	0.100	<.9
-13					

ELATION BETWEEN FECUNDITY AND WEIGHT

The fish used for this fecundity study had iginally been preserved in formalin, but many of em were subsequently transferred to alcohol. he fish in alcohol were noticeably different in ppearance from those in formalin. The sub-taneous fat deposits of the formalin preserved h showed through the skin and scales as a white ackground wherever pigment did not conceal em. These fat deposits were not apparent in e alcohol preserved fish. The formalin preserved fish also weighed considerably more than alcohol preserved fish of comparable lengths from the same sample.

Only a few fish from sample SP–11 were in a jar containing alcohol, and of these only one was a female for which ovum counts were made. The weights of the other 40 females for which ovum counts were made are plotted in figure 7 as the independent variable, with numbers of ova as the dependent variable. Two different regression lines have been fitted to the data.

As will be shown for this sample, the weight [3] of a sardine is a much better indicator of its fecundity than is its length. It can also be shown that for practical purposes the Y-intercept can be taken as zero in the fecundity-weight regression without any significant loss of accuracy (table 5).

TABLE 5.—*Comparison of two fecundity-weight regressions*

Item	$Y=a+bX$	$Y=bX$
a	+2.94	0.0
b	.2402	.2628
S_y	4.91	4.92
r	.624	.622

The use of the formula $Y=bX$ enables one to determine directly the total weight of spawning

[3] The weight used is round weight. If the ovary weight is subtracted from the round weight, the regression is not changed significantly ($a=+3.3$, $b=0.25$, $S_y=5.1$, $r=0.60$).

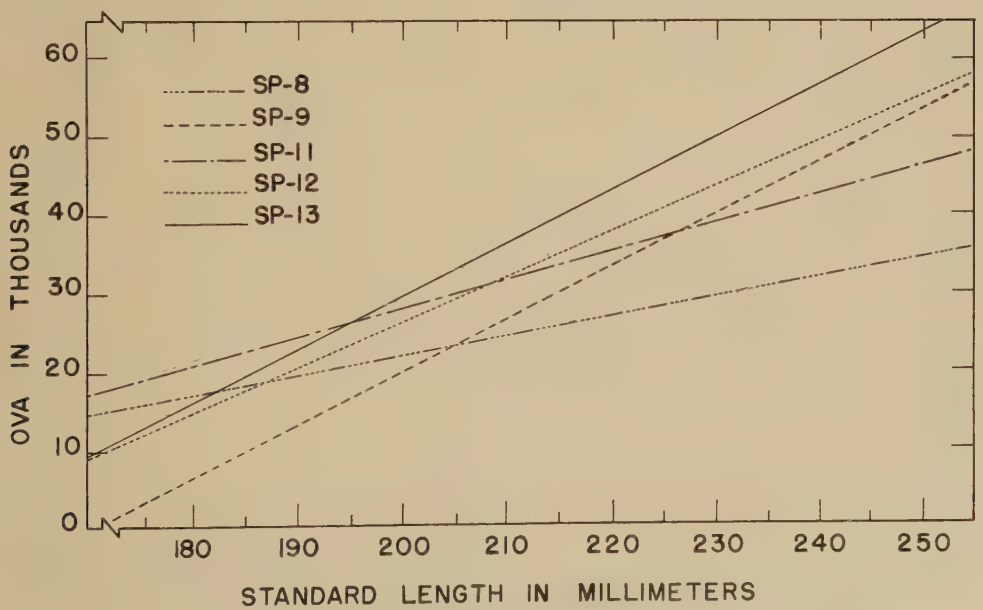


FIGURE 6.—Fecundity-length regression $Y=a+bX$.

female sardines required to produce the estimated number of ova present on the spawning grounds for any one season (assuming that each sardine spawns only the most advanced mode of ovarian ova). If the weight-fecundity relation of sample SP–11 is taken as representative of that of the stock of spawning sardines, the weight of spawning females can be easily estimated on the basis of 262.8 ova per gram or 238.4 million ova per ton of spawning female sardines.

COMPARISON OF FECUNDITY-LENGTH AND FECUNDITY-WEIGHT REGRESSIONS

It has been shown that for the size-range of sardines in these samples, there is very little difference among the regression lines of fecundity on length, on length squared, or on length cubed. For purposes of comparison, the fecundity-length regression line was computed for the same 40 fish used for the fecundity-weight regression line. The partial regression coefficients and the multip regression of fecundity on length and on weigh were also computed (table 6). It would appe from this comparison that the fecundity of the sardines is not only better correlated with th weights, but that the correlation with length merely a reflection of the very good correlati between length and weight.

This comparison may be tested further by t use of condition factors (Clark 1928). In t present case the condition factor, K,[5] equals t weight of the fish in grams divided by the cube the length in millimeters and multiplied by 1 (to give a three-digit whole number). Conditi

[4] Over this length-weight range the cubic relation of length to weigh obscured, and the length-weight regression will approximate a straight l

[5] The use of condition factors "corrected" by subtracting the ovary we from the fish weight before computing K gives results that are almost ident to those obtained from K computed from round weight. Theoretically might also be argued that the fish which contained more ovarian ova or la ova, or both, had produced them at the expense of other tissues and th fore the inclusion of ovary weight in fish weight should have a correc value rather than the opposite.

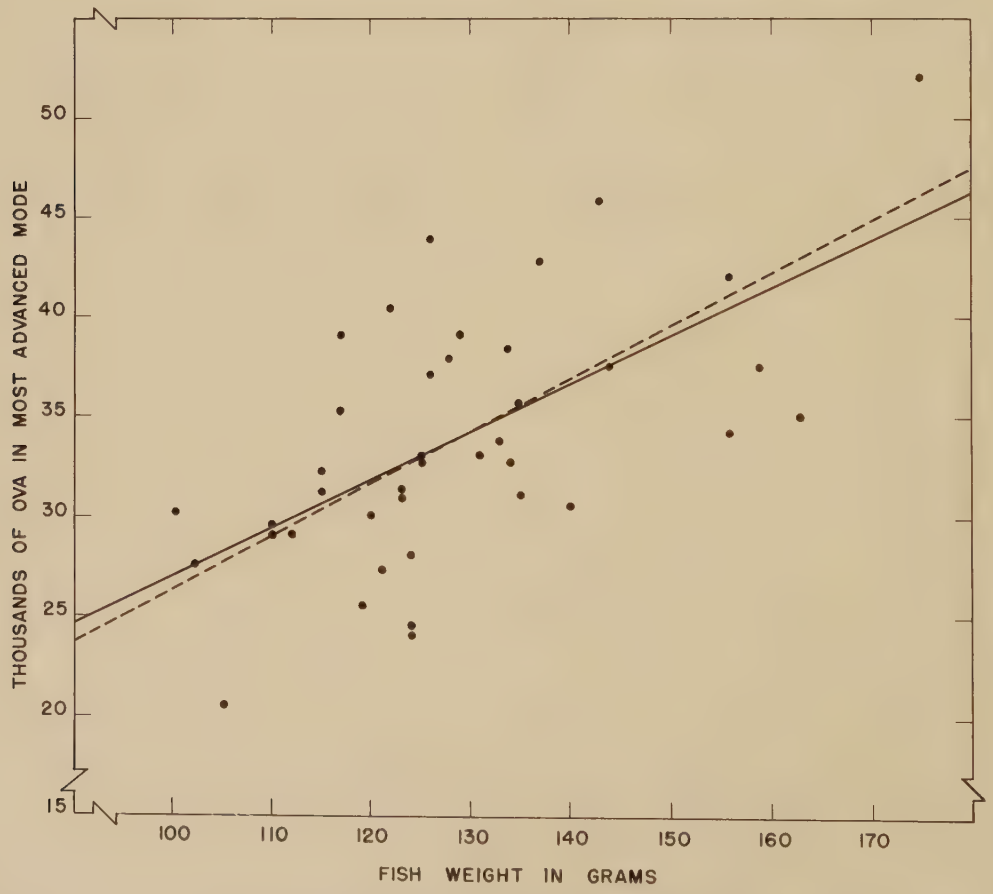


FIGURE 7.—Relation between fecundity and fish weight for 40 sardines (San Pedro, Feb. 9, 1946). (Dashed li $Y=.2628X$; solid line, $Y=2.94+.2402X$).

tors in theory (assuming isometric growth in dimensions) should be comparable for all lengths fish. It appears that condition factors actually comparable among sexually mature fish but between adult and juveniles. The latter usu- have lower condition factors.

In figure 8 the deviation (observed number of a minus calculated number of ova) of each of e 40 fecundity-length pairs is plotted against e respective K value for each fish. The regres- n line is described by $d=.3720K-47.91$ ($S_y=$ 1; $r=.500$). If this equation is added to the undity-length regression as a correction for ferences in K values among the sardines, the ulting equation is $Y=.3534X+.3720K-90.06$. is decreased from 5.55 (for the fecundity-length uation alone) to 4.81, and r is improved from 9 to .644.

BLE 6.—*Comparison of fecundity-length and fecundity-weight regressions*

Item	Fecundity-length	Fecundity-weight	Length-weight	Fecundity-length-weight
	−42.15	+2.94		+41.98
ength)	+.3534			−.2469
veight)		+.2402		+.3494
	5.55	4.91		4.80
	+.469	+.624	+.875	+.646
artial)	−.204	+.500	+.844	

In figure 9 the deviation (observed number of a minus calculated number of ova) of each of the 40 fecundity-weight pairs is plotted against the K value for that fish. The regression line is described by $d=.2565K-33.03$ ($S_y=4.71$; $r=.282$). When this equation is added to the fecundity-weight regression, S_y is decreased from 4.91 to 4.71 and r is improved from .624 to .663.

The comparatively large improvement resulting from applying this K value correction to the fecundity-length correlation, the magnitude of the correlation coefficient, and the positive slope of the regression of fecundity-length deviation on K value, all demonstrate that when two fish are the same length, the heavier fish contains more ova. The positive slope of the regression of K value and fecundity-weight deviation suggests that when two fish are the same weight, the shorter fish will have a higher fecundity, but the low r value (P between .05 and .1) and the small improvement resulting from applying the correction to the fecundity-weight correlation throw doubt on the significance of this correction. It would probably be safe to say that within reasonable limits the fecundity of the sardine is more closely associated with weight than with length.

When fecundity data obtained in one year are used in estimating sardine populations in other years, either the fecundity-weight or fecundity-length relation, adjusted for K, should give a more nearly accurate estimate of ova spawned per female than the unadjusted fecundity-length rela-

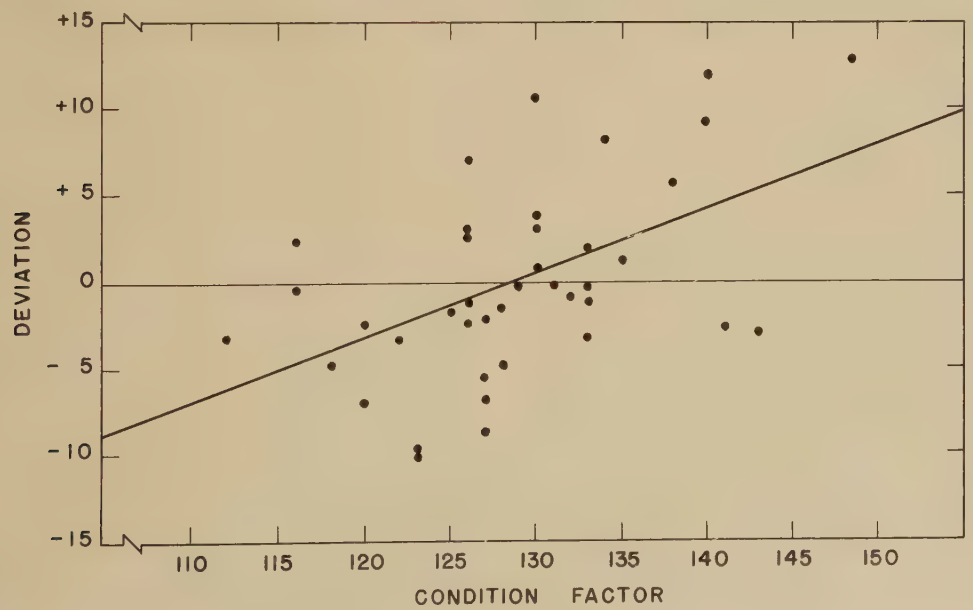


FIGURE 8.—Deviations of fecundity-length regression plotted against condition factor (sample SP–11).

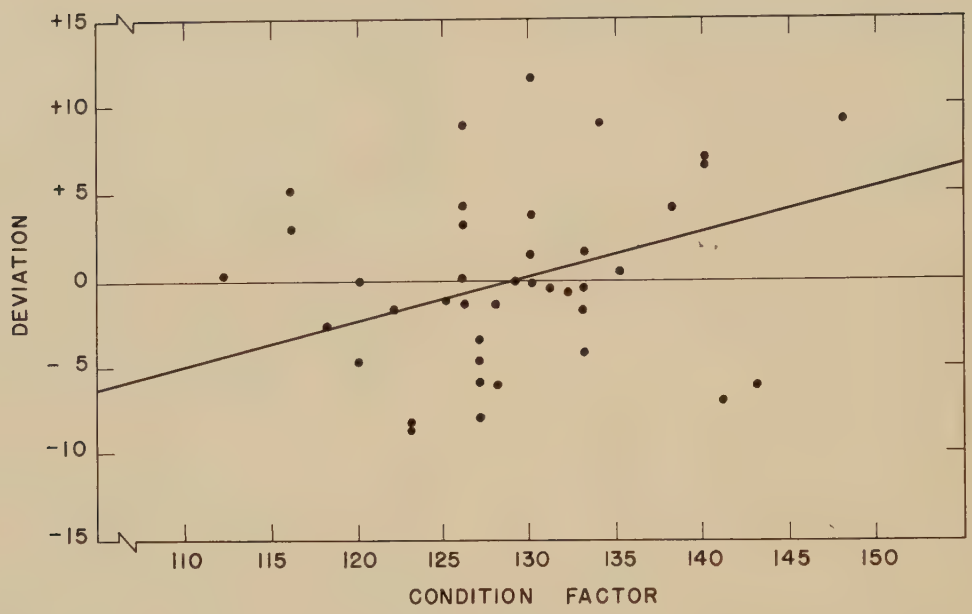


FIGURE 9.—Deviations of fecundity-weight regression plotted against condition factor (Sample SP-11).

tionship. From an examination of weight-length data of commercial fishery sardine samples over a 12-year period, it is evident that the average K value of the sardine population varies greatly not only within a year but also from year to year.

Included in the data recorded in the course of routine sampling of the commercial sardine fishery are the individual lengths of the 50 sardines that make up a sample and their total weight. An approximate K value can be obtained for any sample by dividing the mean-sardine-weight that sample by the cube of the mean-sardi length of that sample. An approximate K tained by this method for the 40 sardines u for the weight-fecundity regression in this pa is 128.87; the mean K value for these same is 128.55. Approximate K values obtained fr the San Pedro commercial fishery samples January of various years illustrate how m year to year variation can occur (table 7).

TABLE 7.—*Condition factors of sardines collected in January during 1941–42 to 1953–54*

Season	Month and year	Average length in millimeters of sardines in 50-fish sample—													
		170–179		180–189		190–199		200–209		210–219		220 and above		All sizes	
		No. samples	Av. K	No. samples	Av. K	No. samples	Av. K	No. samples	Av. K	No. samples	Av. K	No. samples	Av. K	No. samples	
1941–42	Jan. 1942	2	117	12	116	39	117	6	117	1	110			60	
1942–43	Jan. 1943	1	112	5	118	30	118	17	118	1	120			54	
1943–44	Jan. 1944			16	121	30	122	12	124	3	124	2	123	63	
1944–45															
1945–46	Jan. 1946					2	126	9	124	8	127	1	128	20	
1946–47	Jan. 1947			2	115	1	126	5	129	6	128	2	128	16	
1947–48	Jan. 1948	1	123	3	131			2	132	4	132			10	
1948–49	Jan. 1949			1	129	4	128	5	127	1	132			11	
1949–50	Jan. 1950			2	113	3	121	6	124	4	127			15	
1950–51	Jan. 1951							1	124	28	127	1	128	30	
1951–52	Jan. 1952							8	129	2	125	9	130	19	
1952–53	Jan. 1953											5	137	5	
1953–54	Jan. 1954											3	134	3	

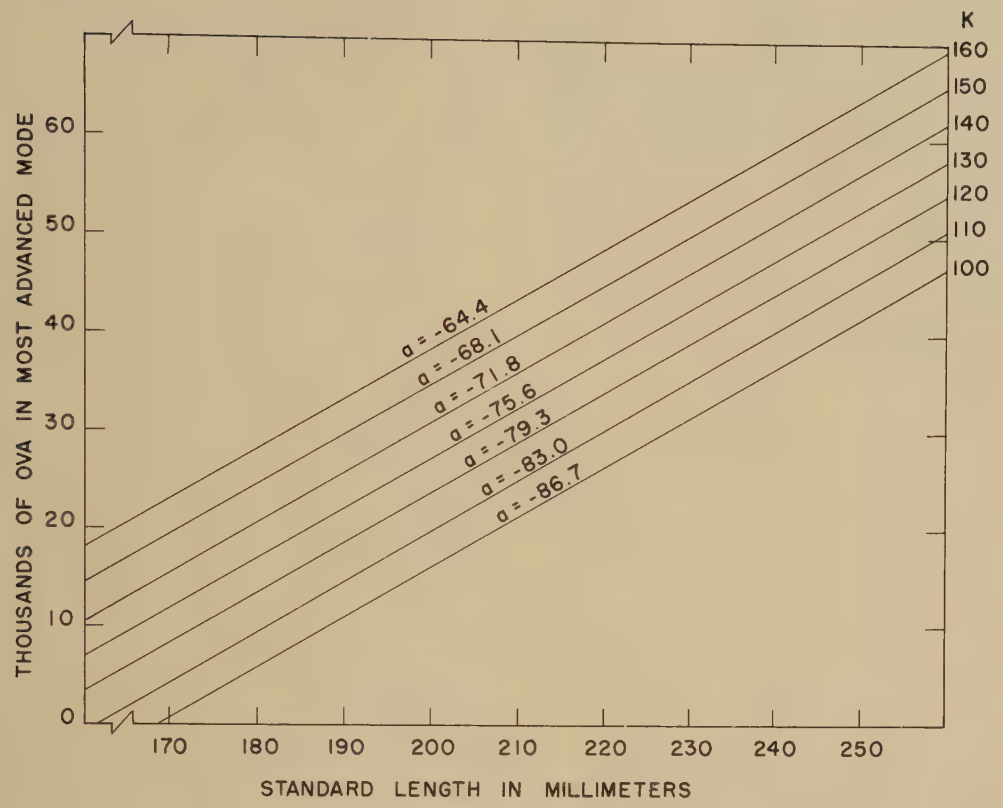


FIGURE 10.—Regression line $Y=0.514X-76.0$ adjusted for various K values by formula deviation$=.372K-47.9$.

n figure 10 are plotted the regression lines of undity-length for the 116 sardines adjusted for ious K values on the basis of the computed iation values owing to K (weight correction) nd in sample SP–11. On the basis of this ure it can be seen that a 20-unit K value differe between two groups of sardines of similar gth distribution would result in a difference of thousands of ova in the most advanced group developing ovarian ova for each fish. The ove is, of course, purely theoretical when applied years other than 1946. Sample SP–11 is probly representative of the population present in San Pedro area in January and February of 6 with respect to K. The mean K value of nple SP–11 (taken on Feb. 9, 1946) is 128.6. e approximate mean K value obtained from ty-four 50-fish samples from the San Pedro mmercial fishery in January and February of 6 is 128.1. What actually happens in years very high or very low K values of the Pacific sardine may be very different from what can be postulated to happen on the basis of fecundity values extrapolated to these high or low K values. The pre-spawning-season condition of a fish may determine not only how many ova will develop per batch of developing ova, but also how many batches will spawn, or if spawning, will take place at all in that season.

RELATION BETWEEN FECUNDITY AND AGE

The mean lengths of each age group are compared with those obtained by Phillips (1948) for the 1945–46 commercial sardine fishing season at San Pedro in table 8. The sampling method upon which Phillips' data are based was designed to sample the commercial catch representatively throughout the fishing season. Although he used fewer fish, a much larger number of samples are included in his data.

Age-fecundity data are presented in figure 11 and table 9 for the 113 sardines for which both fecundity data and age data were available. These show that the correlation between fecundity and age is not so good as that between fecundity and length or weight for these samples. Simpson (1951) also found a poorer correlation between age and fecundity than between fecundity and length or weight for plaice. On the other hand, Lehman (1953) obtained a better correlation between fecundity and age than between fecundity and length or weight for shad.

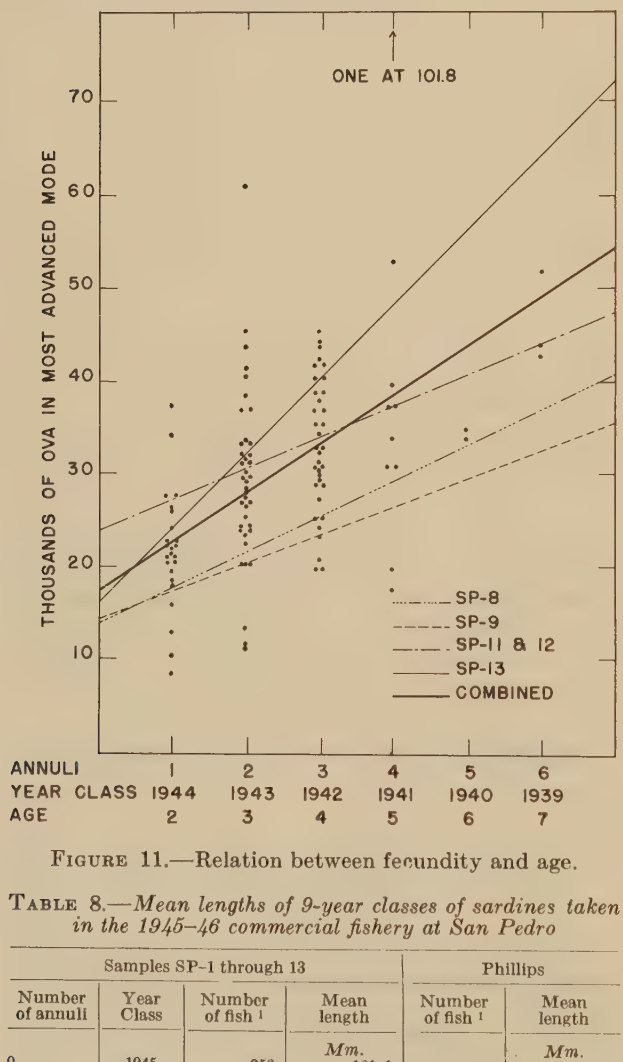


FIGURE 11.—Relation between fecundity and age.

TABLE 8.—*Mean lengths of 9-year classes of sardines taken in the 1945–46 commercial fishery at San Pedro*

Samples SP-1 through 13				Phillips	
Number of annuli	Year Class	Number of fish [1]	Mean length	Number of fish [1]	Mean length
			Mm.		*Mm.*
0	1945	256	161.1		
1	1944	299	184.0	105	182
2	1943	369	199.4	337	200
3	1942	215	210.7	242	206
4	1941	74	213.4	151	213
5	1940	28	227.1	44	218
6	1939	10	244.0	14	224
7	1938	4	237.5	1	248
8	1937	4	245.5	1	254
		1,259		895	

[1] Males and females.

TABLE 9.—*Age-fecundity regression data using fo*
$Y = a + bX$ (Y = *No. of ova in most advanced mode*
No. of annuli [1])

Sample	Number of fish	*a*	*b*	*Sy*
SP-8	17	14.0	3.83	5.64
SP-9	9	14.5	2.97	7.52
SP-11	39	24.0	3.36	5.66
SP-12	5	23.8	3.38	5.56
SP-13	43	16.4	8.00	11.28
All	113	17.7	5.28	9.82

[1] Number of annuli+1=age.

NUMBER OF SPAWNINGS PER YEA

The maturing ovaries of a sardine co yolked ova of two or more size groups. point was illustrated in figure 2. Clark (1 pointed out this fact and used it as a basi concluding that individual sardines spawn than once during each spawning season. A number of batches of ova spawned per seas as critical a point in determinations of fecu as the number of ova spawned per batch, much more difficult to assess, I will review dence for and against multiple spawnings.

The data presented in this paper are base sardines collected during the period Nove 1945 through February 1946. It is unlikely any of the sardines had spawned during period. These months, with the possible e tions of January and February (when no amounts of spawning have been found), a advance of the sardine spawning season in southern California area. As no samples available after February in 1946, the changes took place during and after the spawning se could not be studied. However, some of the obtained from the January and February sa do bear on the problem of multiple spawning these will be summarized.

It is assumed by workers on fecundity that ova in the most advanced mode will be spa at a given time or batch. Hence, the numb ova in this mode is taken to represent the nu of ova spawned per batch. The ratio of numb smaller yolked ova to number of ova in the advanced mode has been taken as an indicati the number of batches that could potentiall spawned in a season. The number of yolke found in a mature ovary just prior to the i spawning of a season would represent the number of ova spawned in that season if (1 the yolked ova were subsequently matured spawned, and (2) if no ova were subsequ added to the group of yolked ova.

Although the 1946 data are too restricted in time show any trend in ratios of ova in the largest de to smaller yolked ova during the spawning son, they are of value in showing the ratios nd in maturing ovaries during January and ruary. The data are summarized by stage of elopment in table 10.

There are three aspects of this tabulation to ich I would like to call attention: (1) There is change in ratio between stages *E*, *F*, and *G* (as ined by Clark 1934:13). This indicates that additional ova were being added to the group smaller yolked ova while the more advanced up was developing from stage *E* to *G*. (2) ere is marked variation in the ratio of large to small in different fish; this is equally true he largest mode is in stage *E*, *F*, or *G*. The ge in ratios is from 0.3 to 3.2. (3) The ratios markedly lower than those reported for San lro in January–February of 1929 and 1930 by rk (1934).

The ratios given by Clark for 3 ports and several sons are summarized in table 11. Clark com- ed the ratio of ova in stage *G* (the last abundant ge before the ova become translucent and are wned) to those of all smaller yolked ova. The ios reported by Clark (table 11) during January l February 1929 and 1930 at San Pedro are ut twice as large as those I found for the same months in 1946 (table 10). A discussion of Clark's data is given in the latter part of this section.

TABLE 10.—*Frequencies of ratios of all smaller yolked ova to the number of yolked ova in the most advanced group at San Pedro in January and February 1946*

Ratio	Stage (after Clark 1934) of most advanced group of developing ova				Total
	D	*E*	*F*	*G*	
	Median diameters				
	.34–.43	.44–.53	.54–.63	.64–.73	.34–.73
0.0					
.1					
.2					
.3				1	1
.4		1			1
.5			1		1
.6					
.7		1	2		3
.8		2	1	1	4
.9		1	1	2	4
1.0		1	4	2	7
1.1	1	4	1	2	8
1.2		2	3	3	8
1.3		4	5	2	11
1.4	1	3	5	4	13
1.5		4	5		9
1.6			4	1	5
1.7		2	3	2	7
1.8		4	3	1	8
1.9		3		1	4
2.0		2	2		4
2.1		1		2	3
2.2			3	1	4
2.3					
2.4			1		1
2.5				1	1
2.6			1		1
2.7		1			1
2.8					
2.9		2		1	3
3.0					
3.1					
3.2				1	1
Number	2	38	45	28	113
Mean ratio	1.3	1.5	1.5	1.5	1.5

BLE 11.—*Ratios of all ova between 0.20 and 0.59 mm. (stages B to F) to all ova larger than 0.59 mm. for all females in stage G (from Clark, 1934, table 1, p. 17) and number and percentage of adult female sardines in stage G (mode .64–.73 mm.) and stages A (resting-mode between 0 and 0.20 mm.) and L (spent) (after Clark, 1934, table 7, San Pedro, p. 27; table 8, Monterey, p. 30; table 9, San Diego, p. 32)*

Date	Monterey					San Pedro					San Diego				
	Ratio stages B–F/G	Stage G		Stages A and L		Ratio stages B–F/G	Stage G		Stages A and L		Ratio stages B–F/G	Stage G		Stages A and L	
		Number	*Percent*	*Number*	*Percent*		*Number*	*Percent*	*Number*	*Percent*		*Number*	*Percent*	*Number*	*Percent*
1929															
II:23		0	0	2	7	3.36	9	17	0	0					
-III:25	5.06	3	10	0	0	3.80	18	33	0	0					
6–IV:23		1	33	1	33	2.87	10	50	1	5					
4–V:23	3.96	2	7	22	76	2.38	5	9	1	2					
-VI:21	4.16	2	10	18	90	2.26	6	17	6	17					
2–VII:21	2.17	0	0	30	97	2.39	2	25	2	25					
22–VIII:20	2.88	0	0	20	95	2.07	5	14	6	17					
:21–IX:18		0	0	42	100	2.11	2	4	36	77					
9–X:18		0	0	33	100		0	0	40	100					
1930															
II:13	3.88	2	4	8	14	2.95	9	18	0	0	2.34	8	28	0	0
-III:14	3.72	5	14	5	14	3.06	17	33	2	4	2.71	32	65	0	0
5–IV:13	2.85	16	47	2	6	2.02	20	37	5	9	3.12	13	62	0	0
4–V:12	2.22	14	44	9	28	2.92	2	9	3	13					
-VI:11	2.42	2	7	23	85	2.84	16	48	7	21					
1931															
I:3		0	0	16	37		2	5	4	11					
III:4		2	6	2	6		12	27	0	0					
-IV:2		19	60	0	0		15	34	0	0					
-V:2		20	69	1	4		2	6	0	0					
V:31		2	6	27	84		2	6	2	6					

I interpret the differences in the ratios between 1929–30 and 1946 as real. I seriously question that they could be due to differences in techniques or interpretation of modes by Clark and myself. There have been three investigators working on the data I have presented in table 10, and the three of us have obtained comparable results. If the ratios are any indication of the average number of batches spawned per female sardine, then the number of batches must vary considerably from year to year. One implication of this is that when basing population estimates on egg surveys and fecundity data, it may be necessary to have current determinations of both egg abundance and average fecundity for that season.

I find that there is no significant difference among ratios of the 113 females considered in table 10 when grouped by size (standard length) rather than stage of maturity (table 12). Clark postulated that larger fish mature earlier than the smaller fish and spawn over a longer time interval. My study does not indicate a higher ratio (of smaller ova to ova in the most advanced mode) in larger female sardines. Hence, if larger fish spawn more batches of eggs in a season than smaller fish, these additional batches are not evident in maturing ovaries. Therefore if larger fish are to spawn more batches of ova than smaller fish, one of the following two conditions must be fulfilled: either additional ova are added to the mass of smaller yoked ova from the reservoir of non-yoked ovocysts, or, if this does not occur, then larger fish must spawn a larger proportion of the smaller yoked ova present in the initial maturation period than do smaller fish. If the first condition obtains, then there would be little significance to ratio changes during the season. If the second condition obtains, then only part of the smaller yoked ova initially present in the developing ovary would eventually mature and be spawned. Hence, smaller fish should have a larger number of batches of degenerating ova at the termination of their spawning than the larger fish. With regard to the 1946 samples, the average ratio of 1.5 to 1 shows that an average of only 2.5 batches could be spawned if all yolked ova were matured and spawned, and no additional yolked ova were added during the spawning season. If a portion of these degenerate, then the average number of batches spawned per female sardine must be between 1 and 2.5 batches.

Andreu (1951) postulated that the peak spa
ing season of the European sardine, as measu
by the occurrence of planktonic eggs (Hick

TABLE 12.—*Frequencies of ratios of number of all sm
yolked ova to the number of yolked ova in the most adv
group (taken as unity) grouped by fish size (star
length)*

Ratio	Fish length in millimeters								
	170–179	180–189	190–199	200–209	210–219	220–229	230–239	240–249	250–
0.0									
0.1									
0.2									
0.3		1							
0.4					1				
0.5								1	
0.6									
0.7			1		2				
0.8		1	2			1			
0.9		2	2						
1.0			2	1	2	2			
1.1			1	5	1				1
1.2		1	1	3	3				
1.3		1	4	1	2	3			
1.4	1		3	4	4		1		
1.5			1		6	2			
1.6			3	1	1				
1.7		1	2	1	2			1	
1.8			1	2	3	2			
1.9		1	1		2				
2.0					1	2	1		
2.1			1	1	1				
2.2				1	1	2			
2.3									
2.4					1				
2.5						1			
2.6		1							
2.7					1				
2.8									
2.9			1		1		1		
3.0									
3.1									
3.2					1				
Total	1	9	26	20	36	15	3	2	1
Mean ratio	1.4	1.3	1.4	1.4	1.6	1.6	2.1	1.1	1.1

1945) off Plymouth, was too restricted in
to allow the sardines to mature and spawn
than one modal group of eggs in a spaw
season. This could also be inferred for
Pacific sardine from table 12, and the o
growth rates postulated by Clark (1934
". . . probably slightly more than two mo
are necessary for eggs to grow from sta
[last mode between 0.26 and 0.34 mm.] to
G [last mode between 0.64 and 0.74 mm.],"
". . . approximately three or four weeks
elapse before females in stage G reach matur

Clark's figures show modal egg diameters
groups of translucent ova ranging from 0.8
over 1.30 mm. According to Ahlstrom (1950
135), "Fertilized eggs average about 1.70 m
diameter (range 1.35–2.05 mm.)," pre-clea
eggs "taken during the four hour period b
midnight are considerably smaller in dian
than are those with some embryonic developm
Since the yolks are of similar size in both gr

difference lies in the width of the perivitelline ce, which is nearly wanting in pre-cleavage s taken during this period; such eggs averaged y 1.20 mm. in diameter (range 1.02–1.38 mm.)." Measurements of the yolk diameters of 343 dine eggs (fig. 2i) from 8 plankton samples en at various times and localities showed mean yolk diameter to be .84 mm. (range -1.00). The mean egg diameter was 1.66 nge 1.40–1.90), indicating that this group of s is comparable with those constituting Ahlom's data (mean=1.70 mm.). One sardine of se used for this study contained translucent ked ovarian ova. The mean of 118 diameter asurements of these ova was .84 mm. (range -.96 mm.). As there was no perivitelline ce, these measurements are also yolk diameter asurements. Clark's (1934) larger diameter asurements of ovarian ova apparently include perivitelline space as well as the yolk and refore are not comparable with the ovarian , .20 to .84 mm. (mean diameter), which lude yolk diameter only. Referring to sardines taining translucent, yolked ovarian ova, Clark 34:11) states, "In the 11 years of study only have been found among the thousands of ales which have passed under observation." is would indicate that this stage is very transiy.

In table 13 I have summarized data on the gth of the spawning season off southern Calinia as determined from sardine egg surveys. tween 70.7 and 97.2 percent of the spawning his area occurred within a period of two months, l between 88.2 and 99.6 percent occurred hin a period of 3 months. The peak month alicized in table 13) was different in each year, icating the amount of variation that can ur in the time of spawning.

Clark (1934:19) bases the case for multiple wning in the sardine on four lines of evidence: he multiplicity of modes in the ova diameter

BLE 13.—*Percent of spawning occurring in each month f 1940 and 1941, 1950, and 1951 spawning seasons off outhern California* [1]

Year	Feb.	Mar.	April	May	June	July	Aug.
----------	11.0	29.7	*41.0*	18.3	-------	-------	-------
----------	17.0	*47.1*	24.1	8.7	3.1	-------	-------
----------	0.0	0.0	2.4	21.3	*75.9*	0.4	0.0
----------	0.0	1.3	1.3	*69.5*	25.9	2.0	0.0

Based on sardine egg survey data given by Sette and Ahlstrom (1948) Ahlstrom (1954).

frequency curves; the high degree of correlation between the growth of these successive groups of eggs; the occasional presence in the ovary of a few ripe unspawned eggs accompanied by a new ripening group; and the decrease, as the breeding season advances, in the numerical ratio between succeeding batches of eggs and the largest size group . . ."

The presence of different size-groups of yolked ova in the developing ovaries of any species of fish has been accepted by various authors as a, if not the criterion of the existence of multiple spawning in that species. However, it is also known that in a number of species of fishes at least some of the yolked ova of intermediate size are not spawned, but instead degenerate and are resorbed. This does not necessarily mean that none of the intermediate-sized ova will be spawned. Clark (1925) concluded that multiple spawning occurred in the grunion (*Leuresthes tenuis*). The ovaries of these fish contained a group of intermediate-sized yolked ova from which a group of ova to be spawned developed and segregated by size at approximately two-week intervals. At the end of the spawning season Clark (1925 : 22) found that, "In all cases, eggs in the intermediate group were undergoing a process of degeneration and resorption."

Hart and McHugh (1944) figure the distribution of ovum diameters for three species of Osmeridae found along the Pacific Coast of British Columbia. As these three species participate in inshore runs their spawning activities are much better known than those of species that spawn offshore.

One of these species, the eulachon (*Thaleichthys pacificus*), migrates into rivers to spawn. The spawning migration lasts from mid-March to mid-May. Each female apparently spawns only one batch of ova; the ovaries of a ripe female contain only the group of matured ova to be spawned and very small ova that contain no yolk.

A similar condition is found in the Pacific herring (*Clupea pallasi*). I had the opportunity to examine five ripe females of this species. I found only one mode of yolked ova, all larger than 1.00 mm. in diameter and the residual non-yolked ova, all smaller than 0.20 mm. This species is a demersal spawner, the eggs being deposited on eel grass and seaweed. The spawning of the one group of matured ova may take

place over a period of several days (Fraser 1922).

Another Osmerid studied by Hart and McHugh (1944) is the silver smelt (*Hypomesus pretiosus*). These fish spawn on beaches during high tides and in most months of the year. The ovaries contain yolked ova of intermediate sizes. Schaefer (1936) has also figured the ovarian ova diameter distributions of this species. The above three authors concluded that this species spawns several batches per season.

The third Osmerid for which ovarian ova diameters are figured by Hart and McHugh (1944) is the capelin (*Mallotus catervarius*). Of this species the authors say, "Spawning takes place in various localities in the strait of Georgia during late September or the month of October . . . Spawning takes place in the evening at high tide right at the water's edge . . . The size frequencies of the eggs [fig. 10] suggest that the mature capelin spawns more than one batch of eggs as there appears to be one group of small eggs becoming differentiated from the general mass which comprise the residual ovarian tissue after the ripe eggs are spawned out. It is not known at the present time whether any such second spawning occurs. It is possible that more or less nomad schools of capelin move around the southern part of the strait of Georgia spawning on suitable beaches as the eggs ripen. There is no racial evidence against such a belief but the only evidence in favor of such a supposition is the observations on the ovaries taken in conjunction with the lack of second spawnings occurring on the same beaches."

Thus we find three possible types of spawning occurring among these shore spawning species: (1) only one group of yolked ovarian ova with only one known spawning (eulachon, herring); (2) more than one group of yolked ovarian ova with multiple spawning (grunion, silver smelt); (3) more than one group of yolked ovarian ova with only one known spawning (capelin).

The degree of correlation between the modal value of the most advanced group of developing ova and the modal value of the secondary group of developing ova was used by Clark (1934) as an indication of multiple spawning in the Pacific sardine. June (1953) also used this method for the yellowfin tuna (*Neothunnus macropterus*). By this method of correlating modal values, Clark (1934) obtained a coefficient of correlation of 0.70 for modal diameters below 0.80 mm. and 0.72 for modal diameters above 0.80 mm.; June (19 obtained a coefficient of correlation of 0.855 his tuna data.

There may be some doubt concerning the int pretation of these correlations because of mathematical restrictions imposed upon the pl ting of the data. Although there are biologi limits to the plotting of any biological data th should be no mathematical limitations; that is should not be mathematically impossible to p any point. In the present case the convention always plotting the larger diameter on one a and the smaller on the other limits the plots t triangular area rather than a rectangular ar It can be demonstrated that while a regress line based on a random plotting of points (posit numbers) in a rectangular area will have a intercept (a) equal to the mean of Y, a slope (b) zero and a coefficient of correlation (r) of zero regression line based on a random plotting points in a traingular area with a hypotenuse slope 1.00 passing through zero (i. e., coincide of the two modes in the present case) will hav Y-intercept of zero, a slope of .500 and a coe cient of correlation of .500.

Regarding the "decrease, as the breeding sea advances in the numerical ratio between s ceeding batches of eggs and the largest group," Clark (1934:19) states: "The change the ratio from approximately 4–1 to 2–1 sugge that each fish may mature an average of th batches of eggs, although this number may higher, for this study furnishes no data to det mine whether growth from the immature to maturing class accompanies growth within maturing sizes."

Her ratio data are given in table 11 along w data on the numbers and percentages of fish stage G (the last abundant stage before the e become translucent and are spawned) and stages A (resting) and L (spent). The data numbers and percentages are based on sardi larger than 199 mm. in length; the ratios app ently include a few smaller sardines in so months.

High percentages of stage G fish were shown Monterey between March 15 and May 13 in 19 and between March 5 and May 2 in 1931 (1929 Monterey data are not used as they based on only 8 stage G fish for the season), lowed in each case by high percentages of stages

ng) and *L* (spent) fish in the next lunar period. would indicate a short peak spawning period e Monterey region during these two years. shows a decrease in ratios in 1930 at Mon- from 3.88 in the January–February period (I:15–II:13) to 2.22 in the April– lunar period (IV:14–V:12). Assuming that alues adequately represent the ratios during wo periods (the higher is based on 2 speci-), the decrease in ratios amounts to 1.66, the average number of batches spawned male could approximate 2.66 batches.

e situation at San Pedro is more difficult to ret. In 1929 Clark shows a high ratio of (based on 18 *G* stage fish sampled between -III:25), a low of 2.07 (based on 5 stage *G* ampled between VII:22–VIII:20) for a total ase in ratios of 1.73; this approximates the ase given above for Monterey in 1930. It l be noted that most of the decrease in ratios 29 at San Pedro also occurred during a two- n period. The ratio of 3.80 had decreased 8 by lunar period IV:24–V:23 for a drop in of 1.4. During the four succeeding lunar ns the further drop in ratios amounted to 0.3. The 1930 data show no real change in during the season. A drop in ratios from o 2.02 occurred between two lunar periods een II:14–III:14 and III:15–IV:13), but the again jumped to 2.92 and 2.84 in the two ing lunar periods.

the end of the spawning period at both ports ning females still contained several modes had not been spawned. These yolked ova have degenerated and been resorbed. In t may be characteristic of fish which mature l modes of ova, that one or more of the s will be resorbed eventually rather than ed.

LENGTH AT FIRST MATURITY

facilitate handling of the data, the samples been grouped by lunar periods [6] in table 14. rk (1934) considered as maturing all those aving a group of ovarian eggs with a modal ter of .22 mm. or larger (i. e., yolked ova).

[6] Pacific sardine fishery in California is carried on at night, when the ols can be located by luminescence. There is generally no fishing he full-moon period. Lunar periods are assigned numbers in con- with the sampling program of the California Cooperative Oceanic Investigations.

Using this criterion, the 250 fish taken in lunar periods 325 and 326 are compared in table 15 with Clark's data for the months of February, March, April, and May of the years 1929, 1930, and 1931.

TABLE 14.—*Samples grouped by lunar periods*

Lunar period	Sample	Date	Number of females
322	SP–1	Nov. 10, 1945	96
	SP–2	Nov. 13, 1945	
323	SP–3	Nov. 26, 1945	119
	SP–4	Dec. 5, 1945	
	SP–5	Dec. 10, 1945	
324	SP–6	Dec. 28, 1945	123
	SP–7	Jan. 5, 1946	
	SP–8	Jan. 11, 1946	
325	SP–9	Jan. 24, 1946	146
	SP–10	Feb. 1, 1946	
	SP–11	Feb. 9, 1946	
326	SP–12	Feb. 21, 1946	104
	SP–13	Feb. 27, 1946	

Maximum ovum diameter, the measurement used to describe the stage of maturity for the 1946 material, is the diameter of the largest ovarian ovum present in a sample of the ovary. An average value (mode, mean, or median) of the group of developing ova cannot be determined accurately for early developmental stages when the developing ova are not completely differentiated from the mass of immature, non-yolked ova that are always present in the ovary. For developing groups of ova that have differentiated enough from these immature ova to form a distinct size group, the maximum ovum diameter is about .07 mm. greater than the median ovum diameter of that size group. This difference is probably less for developing groups of smaller ova than for groups of larger ova.

TABLE 15.—*Numbers of sardines and percentages containing developing ova*

[San Pedro, Calif.]

Standard length (in millimeters)	Lunar period 325 (Jan. 24, Feb. 1 and 11)		(1946) Lunar period 326 (Feb. 21 and 27)		Lunar periods 325 and 326		1929–1930–1931 Clark (1934) (Feb. through May)	
	Total number	Percent maturing	Total number	Percent maturing	Total number	Percent maturing	Total number	Percent maturing
120–129	0		0		0		1	0
130–139	0		0		0		0	
140–149	0		1	0	1	0	4	0
150–159	11	9	24	17	35	14	4	0
160–169	34	29	23	43	57	35	21	24
170–179	8	63	2	100	10	50	21	38
180–189	6	100	10	100	16	100	36	58
190–199	13	92	20	100	33	97	62	89
200–209	25	96	9	100	34	97	83	94
210–219	31	97	9	100	40	98	94	99
220–229	13	100	3	100	16	100	85	100
230–239	4	100	0		4	100	79	99
240–249	1	100	2	100	3	100	75	97
250–259	0		1	100	1	100	67	100
260–269	0		0		0		54	98
270–279	0		0		0		36	100
280–289	0		0		0		10	100
290–299	0		0		0		2	100

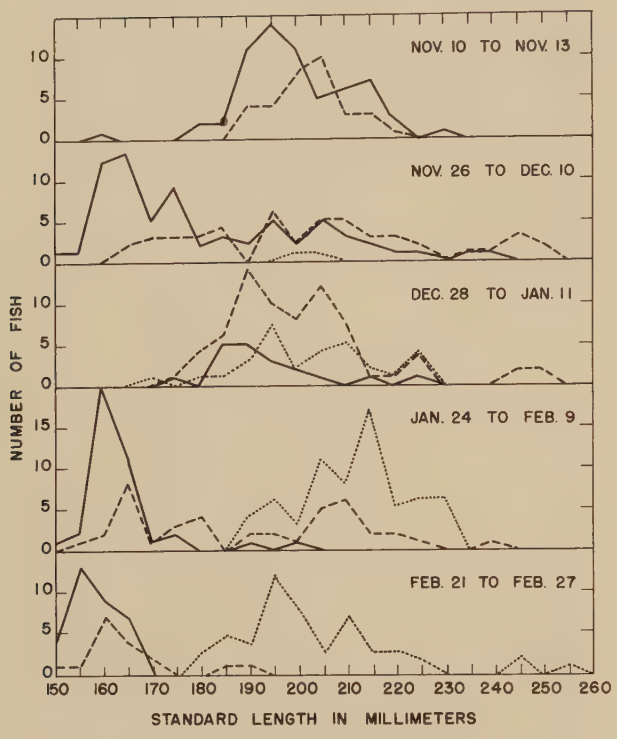


FIGURE 12.—Sardine length frequency distribution for each of three maximum ova diameter ranges (ova to 0.20 mm. solid lines, 0.22 to 0.40 mm. dashed lines, 0.42 mm. and larger dotted lines).

Figure 12 shows fish length-frequency distributions for each of three maximum ovum size ranges and for each of the five lunar periods. The first category of ovum diameters, to 0.20 mm., covers the range of non-yolked ova. The maximum ovum diameter observed for any fish during lunar period 322, when the ovaries were in a "resting" stage, was 0.40 mm.; this size was used as a break between the two categories of yolked ova. This is also the maximum ovum diameter attained by any fish less than 175 mm. in length during lunar period 326, when all but two of the larger fish contained ova that exceeded this value. Table 16 compares maximum ovum diameters of fish more than 175 mm. in length from the November 10 and 13 samples with those under 175-mm. and those over 175 mm., taken in the February 21 and 27 samples.

TABLE 16.—*Comparison of maximum ovum diameta*

Range of ovum maximum diameters	Lunar period 322 Nov. 10 and 13		Lunar period 326, Feb. 21 and			
	Fish more than 175 mm. long		Fish less than 175 mm.		Fish more t 175 mm	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Pe*
to 0.20 mm	62	65	33	69	0	
0.22 to 0.40 mm	33	35	15	31	2	
0.42 and above	0	0	0	0	51	
Total	95	100	48	100	53	

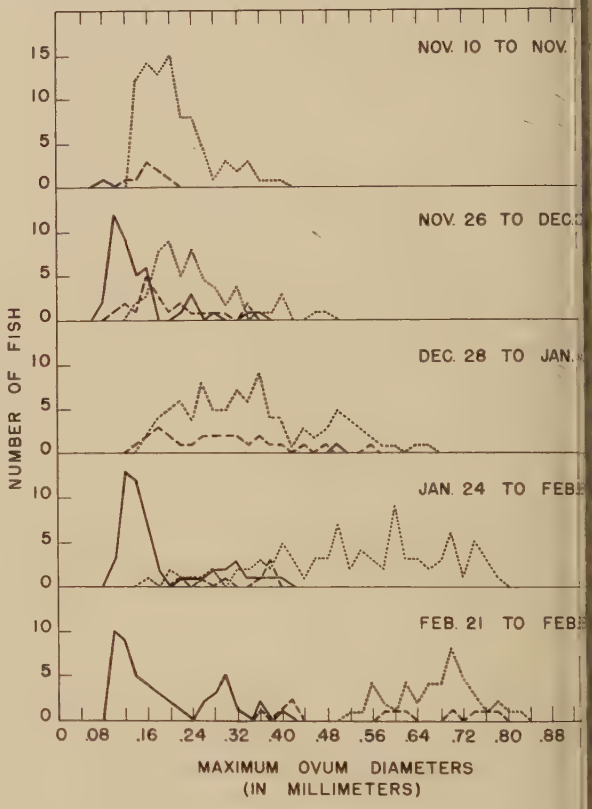


FIGURE 13.—Maximum ovum diameter frequency di bution for each of three sardine length ranges (148 mm. solid line, 175–189 mm. dashed line, 190–253 dotted line).

Figure 13 shows the maximum ovum diam frequency distribution for each of three fish ranges. The above data show a very defi growth of the ova in fish more than 175 mm length and negligible growth of the ova in fish than 175 mm. The state of development of ovaries of the fish less than 175 mm. long in lu period 326 (late February) is very similar to

of development of the ovaries of the fish e 175 mm. in length in lunar period 322 (mid-ember). Clark (1934:22) states that, " * * * escent fish may start to mature eggs but these may fail to reach a ripe state and eventually nerate. Such a condition has been claimed he hake by Hickling (1930), but we have not able either to prove or disprove the possi- for the sardine." As no samples are avail- for the 1946 spawning season after February he ultimate fate of the ovarian ova of these ler sardines cannot be determined. If the ence of yolked ova in the ovary is the criterion aturity, all fish more than 175 mm. in length 31 percent of the fish under 175 mm. in length the samples of February 21 and 27 had ned maturity. If a maximum ovum diameter eding 0.40 millimeters (i. e., the maximum n diameter attained by any fish in the samples November 10 and 13, when the ovaries are ing") is the criterion of maturity, all fish 190 or more in length, 82 percent of the fish 175 9 mm. in length and none of the fish 174 mm. ss in length from the samples of February 21 27 had attained maturity.

AGE AT FIRST MATURITY

Numbers and percentages of sardines at each of three maturity stages for each age group and each lunar period are presented in table 17. If the presence of yolked ova in the ovary is the criterion of maturity, 28 percent of the one-year-old fish and 100 percent of the two-year-old and older fish were maturing in lunar period 326 (samples of February 21 and 27). But the presence of yolked ova in the ovaries may not necessarily mean that a fish will develop and eventually spawn those ova. Actually the one-year-old fish were less advanced in respect to ovarian development in lunar period 326 (samples of February 21 and 27) than the two-year-old and older fish were in lunar period 322 (samples of November 10 and 13).

In any case the one-year-old fish taken by the commercial fishery cannot be considered representative of the one-year-old fish in the population at large. One-year-old sardines are not often taken by the commercial fishery, and those that are taken are undoubtedly the larger specimens of that age group.

TABLE 17.—*Age at first maturity*

Age and year class	Maximum ovum diameter (in millimeters)	Lunar period 322		Lunar period 323		Lunar period 324		Lunar period 325		Lunar period 326	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
old (1945)	0 to .20			25	100			37	82	31	72
	.22 to .40			0	0			8	18	12	28
	.42 and over			0	0			0	0	0	0
tal				25	100			45	100	43	100
-old (1944)	0 to .20	17	71	23	61	4	19	0	0	0	0
	.22 to .40	7	29	15	39	14	67	7	70	5	17
	.42 and over	0	0	0	0	3	14	3	30	24	83
tal		24	100	38	100	21	100	10	100	29	100
-old (1943)	0 to .20	22	59	12	46	13	21	1	3	0	0
	.22 to .40	15	41	13	50	35	56	12	33	0	0
	.42 and over	0	0	1	4	14	23	23	64	17	100
tal		37	100	26	100	62	100	36	100	17	100
-old (1942)	0 to .20	9	47	3	21	3	9	1	3	0	0
	.22 to .40	10	53	10	71	15	43	5	16	0	0
	.42 and over	0	0	1	7	17	49	26	81	6	100
tal		19	100	14	99	35	101	32	100	6	100
ears old (1934–41)	0 to .20	9	69	5	31	0	0	0	0	0	0
	.22 to .40	4	31	11	69	8	80	2	15	0	0
	.42 and over	0	0	0	0	2	20	11	85	5	100
tal		13	100	16	100	10	100	13	100	5	100

SUMMARY

1. Ovarian ovum counts and diameter measurements are presented for 13 samples of sardines containing 587 females taken by the San Pedro commercial fishery during the period November 10, 1945 to February 27, 1946.

2. Throughout the size range of fish studied there are no significant differences among the regression lines of fecundity expressed as the number of ova in the most advanced group of yolked ova on length, on length squared, or on length cubed.

3. The estimated number of ovarian ova present in the most advanced group of yolked ova in a sardine 200 millimeters in length is 26.8 thousands (using the formula $Y=a+bX$). The rate of increase or decrease in estimated numbers of ova is 5.14 thousands per increase or decrease of 10 millimeters of length. There is considerable variation in the number of ova produced by individual fish at any given length. The standard error of estimate of y is 8.76 thousands of ova for the above formula.

4. The correlation between fecundity and fish weight is better than that between fecundity and fish length. The number of ova present in the most advanced group of yolked ovarian ova equals 263 ova per gram weight of sardine.

5. Both the fecundity-length and fecundity-weight correlations are better than the fecundity-age correlation.

6. No conclusions can be drawn from the material used in this study regarding the number of groups of ova that a sardine will spawn in one spawning season. The evidence presented in the literature by various authors is inconclusive and their conclusions are contradictory.

7. All fish two or more years old and all fish more than 175 mm. in length from the February 21 and 27 samples contained yolked ovarian ova (0.22 mm. or larger in diameter); 28 percent of the one-year-old fish and 31 percent of those less than 175 mm. in length also contained yolked ovarian ova. None of the fish in these latter groups contained ova greater than 0.40 mm. in diameter, while 91 percent of the two-year-old and older fish and 96 percent of the fish greater than 175 mm. in length contained ova greater than 0.40 mm. in diameter. The stage of ovarian development of the one-year-old sardines less than 175 mm in length on February 21 and 27 was much like that found in the older and larger fish taken about two months earlier (on November 10 and 13, 1945).

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